

Spillway tainter gate structural details are suggested as appropriate for tainter gates on lock sills (EM 1110-2-2703).

d. Other gates. Navigation inconvenience at lower pool (rising single-leaf vertical lift gates) and clearance for opening at upper pool (submergible or rising single- or double-leaf vertical lift gates) preclude a significant reduction in sill spacing by using narrower gates. Gate designs are discussed briefly in Appendix B and detailed in EM 1110-2-2703. Lock chambers using gates other than miter gates are unusual in CE design practice.

4-3. Sill Spacing

For preliminary layouts, sill spacing is based on usable length and miter gate or sector gate leaf extension; approximately 10 ft is added to provide a combined sill and gate clearance. Final gate selection considers structural, mechanical, and economic factors in addition to hydraulics and may result in an alternate gate and a small change in sill location.

4-4. Location of Intake Structures

The chamber inflow hydrograph (flow rate, Q , as a function of time, t) is finalized during hydraulic feature design; however, estimates of flow are required before these details are known. Intake structures are located so that lockage flows are a minimum liability to navigation and also satisfy other site-specific constraints. Navigation conditions are often determined by means of small-scale hydraulics models (see EM 1110-2-1611 and item F4, for example) which require preliminary estimates of lock inflow rate.

4-5. Lock Filling

CORPS program H5320 or other expedient calculation (item R1, for example) is used to provide Q as a function of t for the lift and geometry of the new lock. Should operation time (T , Chapter 5) be greater than authorized, then system size is increased; additional costs as compared to the existing lock are anticipated. Should operation time be less than authorized, then system size may be decreased. Idealized hydrographs, as shown in Figure 4-2, may also be used to establish preliminary estimates of lock inflow. The volume of inflow, using a discharge Q as a function of time t , is set equal to the change in lock chamber water volume. The following guidelines identify rapid filling times (small T values) for existing designs.

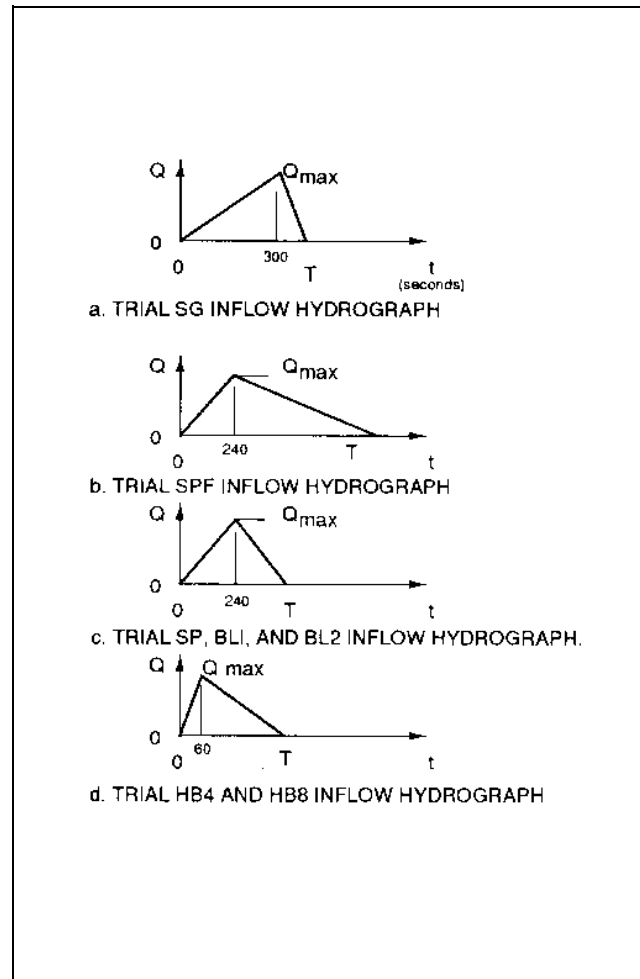


Figure 4-2. Idealized lock filling hydrographs for preliminary estimates of lock inflow

a. Very-low-lift designs. For SG locks, the gate opening rate and pattern are adjusted in the prototype to accommodate various lift, vessel, and approach conditions. For SPF locks, valve pattern and port openings are adjusted in the prototype for the same reasons. Operation times near 10 min (items B9, P2) are the minimum achievable for acceptable chamber performance. For small SG chambers with recreational traffic, lower lifts, and adequate submergence, an operation time nearer 5 min may be appropriate.

b. Low-lift designs. For SP locks, acceptable chamber performance is obtained during hydraulic feature design for a specific filling time and specific commercial traffic (9-ft-draft tows) because of tested relationships between lift, chamber dimensions, submergence, port dimensions, baffles, and valving. An 8-min operation time is a common goal for lifts near midrange, 25 ft. Predesign estimates of SP operation time for an 84-by

600-ft chamber and 4-min valving are shown in Figure 4-3. Neither BL2 nor BL1 designs have as comprehensive a set of operation time versus submergence data as do side-port systems. For these systems, a filling time T of 8 min and a valve time t_v of 4 min are suggested for preliminary inflow estimates for the entire low-lift range.

c. High-lift designs. HB4 and HB8 chamber details are variable during design only with extensive laboratory testing regarding chamber performance. Both systems are designed for rapid valving ($t_v = 1$ min) and rapid filling. Prototype filling times for these systems are estimated in Figure 4-3 for lifts ranging from 40 to 100 ft. Making these systems slower, except by valving, or faster requires significant changes of chamber features.

4-6. Chamber Depth

Chamber depth D_c (Figure 4-4) for design purposes is the depth of water in the lock during navigation lockage conditions. The minimum depth corresponds to the minimum tailwater elevation and the maximum depth to the maximum upper pool elevation for which lockage is planned. The choice of the chamber floor elevation must include safety and economic considerations. The time of entry and the filling/emptying time are decreased while the cost of the structure is increased as the chamber depth is increased. Safety is improved as the chamber depth is increased. The minimum chamber depth must have a filling time that is slow enough not to violate the 5-ton hawser stress guidance. Figure 4-3 is an example. It may be that the sill depth requirements (paragraph 4-7) will limit the minimum chamber depth. An economic analysis using the incremental delays in lock transits for increments of tailwater/headwater durations versus the incremental structural cost of providing various chamber depths is employed to optimize the benefit to cost ratio. Project experience is listed in Table 4-2 and discussed in the following paragraphs. Submergence is defined as the difference in elevation between lower pool and chamber floor. Cushion is defined as the elevation difference between vessel keel and chamber floor for zero velocity conditions.

a. Very-low-lift designs (0-10 ft). These locks have been constructed with chamber floor at navigation channel bed elevation. The submergence has therefore been established by upstream and downstream channel conditions rather than chamber performance.

b. Low-lift designs (10-30/40 ft). The minimum submergence for optimum filling/emptying time for

side-port locks is the tow draft plus one-half the side-port spacing (item 72). For a 9-ft-draft tow in a 110-ft-wide lock, the optimum minimum submergence is $14 + 9 = 23$ ft. When excavation costs associated with deep submergence are significant, then the lateral BL2 system has been used. Using 16-ft submergence plus 7-ft lateral-culvert total height = 23 ft as criterion, then for lifts less than about 25 ft, BL2 is not an economical alternative to SP systems. For lifts above 25 ft, the BL2 design has been used instead of the SP design provided reduced excavation represents a major economic factor as compared to the expense of lateral culverts and risk during single or nonsynchronous culvert operation is operationally acceptable. The high-lift HB4 type of design is expected to be an effective alternative to BL2 designs, although use in 1,200-ft chambers has yet to be studied. The auxiliary lock, BL1, is normally set so that submergence is equal to that of the main lock.

c. High-lift designs (30/40-100 ft). Submergence values are as shown in Table 4-2 for the listed lifts. The extreme excavation measured from lower pool to the lowest invert in the crossover area is 34 ft for HB4 design and 41 ft for HB8 design. The HB8 design with modified crossover culverts has been model-tested for a 69.5-ft lift, 14-ft-draft tows, 5-ft cushion, and 86-ft by 675-ft chamber with no evidence of unsatisfactory performance. The VB4 designs, which have similar manifolds but modified crossovers as compared to HB4, have been model-tested for lifts ranging from 30 to 100 ft for a range of lifts and chamber sizes; prototype experience (see Appendix B) is available with these designs. The HB4 design (modified) was considered for a 130-ft lift, 84- by 600-ft chamber; however, the project was terminated for economic rather than operational reasons.

4-7. Sill Elevation

Sill depth D_s (Figure 4-4) for design purposes is the depth of water over the sill during navigation lockage conditions. The minimum depth corresponds to the minimum tailwater elevation for the lower sill and to the minimum upper pool elevation for the upper sill.

4-8. Sill Elevation Guidance

The choice of sill depth must include safety and economic considerations. As the sill depth is either the same or less than the chamber depth, it becomes the governing factor for safety and tow entrance time. A sill depth less than 1.5 times the tow draft ($1.5d$), except for very-low-lift (0-10 ft) locks, should not be considered

Table 4-2
Submergence Values

Design Type	Project (see Appendix B)					Traffic		Submergence ^b ft	Cushion ^c ft
	Name	Data ^a	Length ft	Width ft	Lift ft	Type	Draft ft		
Very-Low-Lift Projects									
SG	Vermilion	D	110	1,200	5	Tow	9	15	6 [3]
SG	W. G. Stone	D	86	640		Rec. Tow	12 9	15 15	3 [0] 6
SG	Algiers	M	75	800	8	Tow	14	15	1
SG	S-61	D	30	120	Rec.	Tow	9	13.5	4.5
SPF	L&D 52	D	110	1,200	12	NV ^d Tow	7.5 9	NV ^d 12.0	3
Low-Lift Designs									
SP	Willows Is. Main	D	110	1,200	20	Tow	9	25	16
SP	Ozark	D	110	600	34	Tow	9	27	18
BL2	Belleville Main	D	110	1,200	22	Tow	9	28	19
BL2	Markland	M	110	1,200	3	Tow	9	16.5	7.5
BL2	Greenup	M	110	1,200	30	Tow	9	16	7
BL1	Willow Is. Aux.	D	110	600	20	Tow	9	25	16
High-Lift Designs									
VB4	Bay Springs	M	110	600	92	Tow	9	15	6
VB8	Lower Granite	M	86	675	105	Tow	9	17	8

Notes:

- ^a M = model tested for satisfactory chamber performance; D = design normal values. Listing includes projects shown in Plates 3-1 through 3-8.
^b Submergence is lower pool elevation minus chamber floor elevation; values in brackets are minimums.
^c Cushion is submergence minus draft; values in brackets are minimums.
^d NV = no value available; submergence ranges from 7.5 to 9 ft for Kassinnee River Locks.

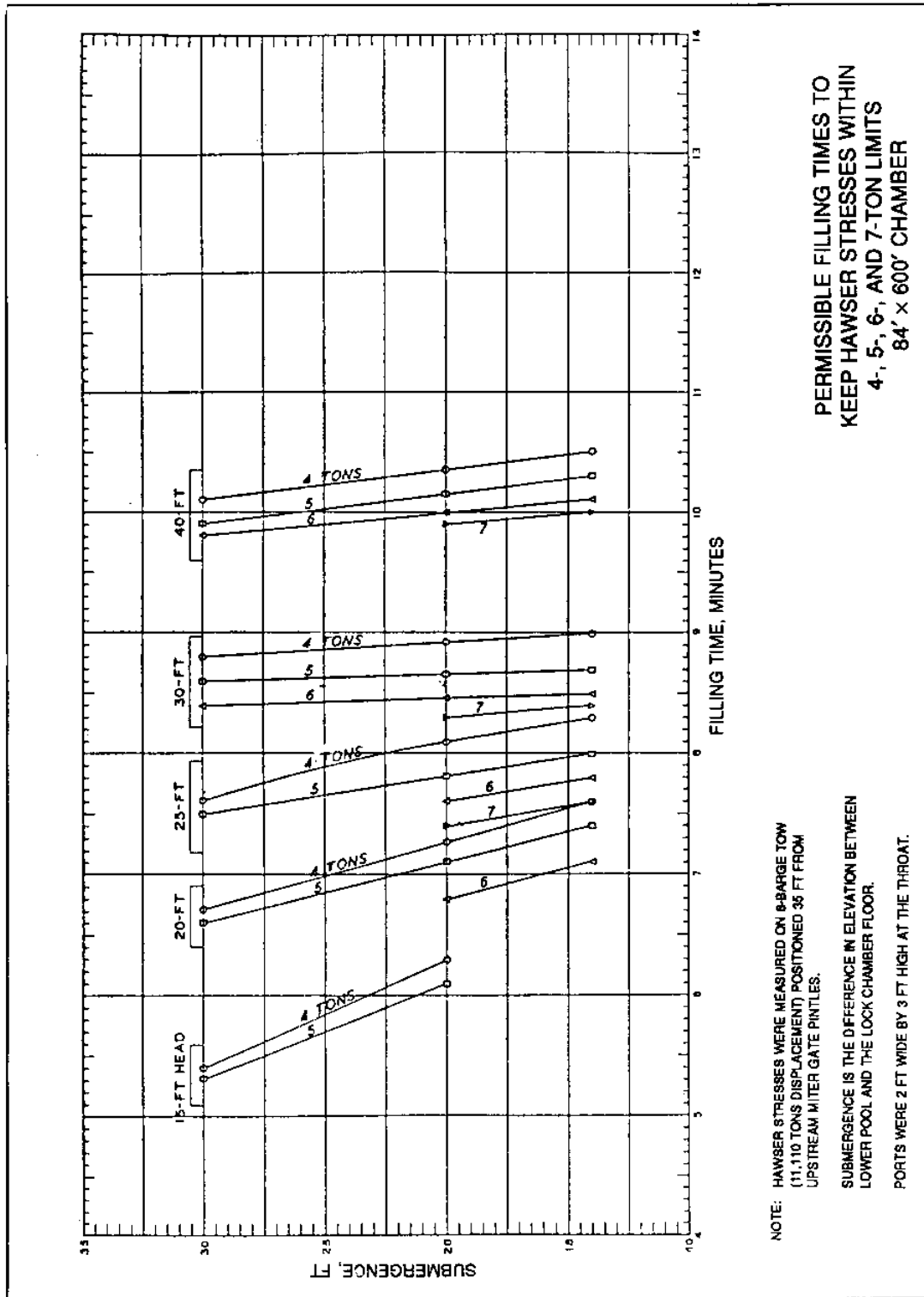


Figure 4-3. Filling time test data. Side-port data are from model tests; the prototype will operate about 10 percent faster

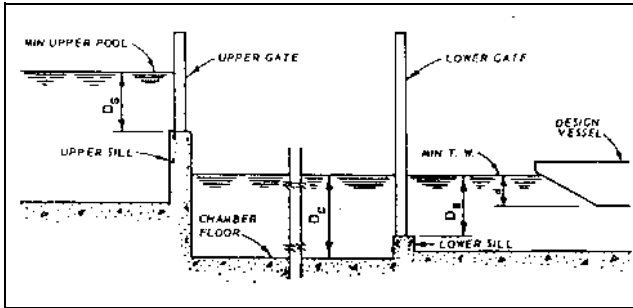


Figure 4-4. Sill elevations

due to safety reasons (item K3). A normal entrance speed of approximately 3 mph requires a sill depth of 2d to avoid excessive squat and loss of vessel speed control. When gate operating clearance above the floor to allow for some accumulation of trash is necessary, either a 2- or 3-ft height of sill above the floor or a floor recess is provided. Since there is very little difference in the cost of the sill versus the cost of the gate, the sill elevation should be kept as low as possible for ease of tow entry and exit and for safety reasons due to the possibility of grounding caused by squat and/or ice accumulation. The upper sill depth should be equal to or greater than the lower sill depth. Consideration can be given to a much greater depth if a need to pass emergency traffic during a loss of pool situation or other exigency is projected. Table 4-3 provides examples of sill depths at some existing projects. The CEWRC-NDC Waterling Bulletin Board System (Navigation and Dredging Data and Reports, Lock Characteristics Data, Physical Characteristics Report) provides a complete listing of Corps locks. The influence of the sill depths due to tailwater and upper pool elevation durations at various levels is part of the economic analysis called for in paragraph 4-6.

Table 4-3
Existing Sill Elevations

Lock	Type	Upper Design ft	D _c ft	Lower D _s D _s ft
Vermilion	SG	15	S	S
Lock 52	SPF	12	15.4	11
Willow Is. Main	SP	25'	35,18 ^b	15
Ozark	SP	27'	18 ⁿ ,16 ^m	17 ⁿ ,14 ^m
Belleville Main	BL2	28'	37,20 ^b	15
Willow Is. Aux	BL1	25'	35,18 ^b	15
Bay Springs	HB4	15	21 ⁿ ,15 ^m	15
Lower Granite	HB8	17	21 ⁿ	15 ^m

Note: S = same as chamber floor; r = rock floor; b = initial; n = normal; m = minimum; values are for normal pools unless otherwise noted.

4-9. Location of Outlet Structures

Constraints are so that lockage flows (emptying) are a minimum liability to navigation and satisfy other site-specific concerns and so that satisfactory chamber performance is retained. For sector gates the outflow point is the lower gates, and discharge is directly into the lower approach channel. For culvert systems the outflow is either into the approach channel (by means of bottom or side manifolds) or, when possible, into the main river remote from the approach, or by a division of flow between main river and approach canal. Three specific preliminary information needs are as follows.

a. Navigation. Discharge hydrographs are required for studies (EM 1110-2-1611) of navigability in the lower approach. Control during emptying is at the outlet ports which, in design, can be modified to increase peak flows (decrease operation time). For preliminary calculation the outflow hydrograph is made identical to the inflow hydrograph (Figure 4-2) although a 10 to 20 percent decrease for peak flow during emptying is not uncommon.

b. Channel stability. Discharge hydrographs are required; the estimates (*a* above) are used for preliminary studies of bed and bank stability. Structures for energy dissipation and stone for bed and bank protection are often required.

c. Stages. For remote outlets, the differential between stage at the outlet location and stage in the lower approach channel affects lower gate operation. Values are required for the navigable range of hydrologic conditions at the project.

4-10. Typical Outlet Locations

The outlet structure types in Table 4-4 are from Plates 3-1 to 3-8.

Table 4-4
Outlet Structure Types

Project (Typical)	Outlet Structure Type
Vermilion	Sector gate
Lock 52	Channel side; one multiported structure
Willow Is. Main	Remote; one with two ports
Ozark	Remote; one with two ports
Belleville Main	Remote; two with one port
Willow Is. Aux.	Remote; one structure with one port
Bay Springs	Channel bed; two multiported structures
Lower Granite	Remote; one structure with two ports

Section II
Very-Low-Lift Designs

4-11. General

Relatively small static and dynamic hydraulic loadings occur for locks with very low lifts (water-surface differential $H < 10$ ft). In addition, constraints with regard to chamber performance (filling time and hawser stress) are normally sufficiently flexible so that adjustments to the field operating procedure, rather than design information, are used to optimize chamber performance. These adjustments are:

a. Sector gate (SG) locks. To obtain satisfactory chamber performance, the gate opening rate, pattern, and duration are finalized in the prototype.

b. Side-port-and-flume (SPF) locks. The number and sizing of open ports are chosen during prototype operation.

Model and prototype hydraulic measurements are unavailable for the SPF locks; these design layouts are patterned after low-lift SP systems. Model data (items 19, 20, and 36) are available for SG locks. More rigid constraints or unusual geometric concerns (see item 13, for example) commonly require physical hydraulic model testing (items B9, B11, S7). Overstressing of SG operating machinery during reverse heads (laboratory studies, item 65; prototype studies, item 66) resulted in gate framing and lip designs presented in EM 1110-2-2703 that have not been rated for lock filling and emptying.

4-12. Sector Gate Design Concept

The gate and recess, shown in Plate 3-1 with EM 1110-2-2703, are geometrically formed so that the minimum dimension between recess lip and recess boundary equals the clear opening at the lock center line. Flow is distributed across the width of the chamber since the recesses, in addition to the center-line opening, are flow passages.

4-13. Hydraulic Evaluation

Sector gate lock studies include four fundamental evaluations:

a. Operation time. Longer filling and emptying times are expected for projects requiring larger chamber water-surface areas or having higher lifts. The size and shape of the flow passages through the gate recesses

affect the rate of flow into and out of the chamber as well as affecting the mooring conditions immediately downstream from the gate. The primary means of altering the operation time for a specific sector gate design is by optimizing the rate and extent of gate opening. The values in Table 4-5 apply to constant rate gate opening tests for the Sacramento Barge Canal Lock; see item 36 for a wider range of test conditions.

b. Chamber mooring conditions. Velocities and turbulence near the upper gate during filling and lower gate during emptying are unfavorable as mooring conditions. For example, a usable chamber length of about 540 ft, rather than 640 ft, based on gate location is suggested (item 36) for the Sacramento Barge Canal Lock. An alternate solution is slow gate operation.

c. Hydraulic loadings. The forces required to open and close the sector gate under normal and reverse flows are sensitive to gate lip shape. Loadings are presented in EM 1110-2-2703 (from items 36 and 65). The more recent results (item 65) are for sector gates operating under reverse heads and provide guidance on gate lip detail.

d. Flow rate. The chamber water-surface elevation is evaluated by simultaneously numerically integrating flow rate Q and elevation z relationships:

$$Q = cb_g h^{3/2} \quad (4-1)$$

$$Q = A_L \frac{dz}{dt} \quad (4-2)$$

where

c = a coefficient that is assumed constant for free-flow conditions, but under submerged conditions gradually decreases with increased submergence (see Figure 4-5)

b_g = effective gate opening which includes the center-line opening and the gaps through the recesses

h = upper pool water-surface height above the upper sill

z = chamber water-surface height above the upper sill

Table 4-5
Constant Rate Gate Opening Tests (Sacramento Barge Canal, Item 36)

Stage ^a ft	Lift ft	Gate Opening Rate deg/min	Filling Time T min	Emptying Time T min	Maximum Gate Opening	
					Filling deg	Emptying deg
34.5	21	0.33	13.7	20.1	4.6	6.7
		0.66	9.4	13.7	6.2	9.0
29.5	12	0.33	12.5	15.1	4.1	5.0
		0.66	8.8	10.7	5.8	7.1
		1.00	7.2	8.8	7.2	8.8
22.5	6	0.33	12.6	14.3	4.2	4.7
		0.66	8.1	10.1	5.4	6.7
		1.00	7.2	7.8	7.2	7.8

Note:

^a Stage is referenced to upper gate sill.

A_L = lock chamber water-surface area

dz/dt = rate of change of the chamber water-surface elevation

Filling is initiated with the upper gates closed and the lock chamber at lower pool level. An example of a calculation for Algiers Lock, item 20, is shown in Figure 4-5. For filling with continuously submerged flow ($z/h > 0.7$), Equation 4-2 in conjunction with the orifice equation is probably more reliable than the above procedure. The flow rate is expressed as

$$Q = cb_g h \sqrt{2g(h - z)} \quad (4-3)$$

in which the coefficient c is about 0.55 (item S7). Concepts associated with wave action in the chamber and inaccuracies associated with flow calculations for sector gate locks are discussed elsewhere (items S7 and R1, for example). Model and prototype experience, with provision for field adjustment of the sector gate opening pattern, is an essential part of the hydraulic design of sector gate locks.

4-14. Side-port Flume (SPF) Designs

Prototype study data are available from the U.S. Army Engineer District, Louisville. These data include valve operation schedules and operation times for lifts experienced at Locks 52 and 53 (temporary locks). Qualitative information regarding port sizing, flume and chamber performance, and operational experience are

also available. These locks have not been model-tested, so generalized design data are not available.

Section III

Culvert-to-Chamber Systems

4-15. General

The arrangement and sizing of the chamber ports affect chamber performance (hawser stresses, for example) as well as operation time. The flow through the culvert-to-chamber system is bidirectional; that is, the ports are discharge orifices during filling and intakes during emptying. These requirements have resulted in a small set of effective designs (SP, BL1, BL2, HB4, and HB8) that are suited to a reasonably broad range of design constraints. Guidance for the hydraulic design of side-port locks, which have been tested for a very broad range of constraints, is presented in Appendix D.

4-16. Chamber Port Arrangements

The layout of lateral (BL1 and BL2) design is based on model tests conducted for Greenup and Markland Locks (item 43). Small variations in locating and sizing the lateral manifolds have been adopted for design and have performed acceptably in the field. The location of the SP manifolds relative to chamber length follows specific guidelines outlined in Appendix D. The location of the longitudinal manifolds (HB4 and HB8) is invariant; i.e., all chamber details are required to be identical to Bay Springs Lock, HB4, or Lower Granite Lock, HB8. These detail dimensions are available in two model test reports (item 78 for HB4 and item 79 for HB8) and in project

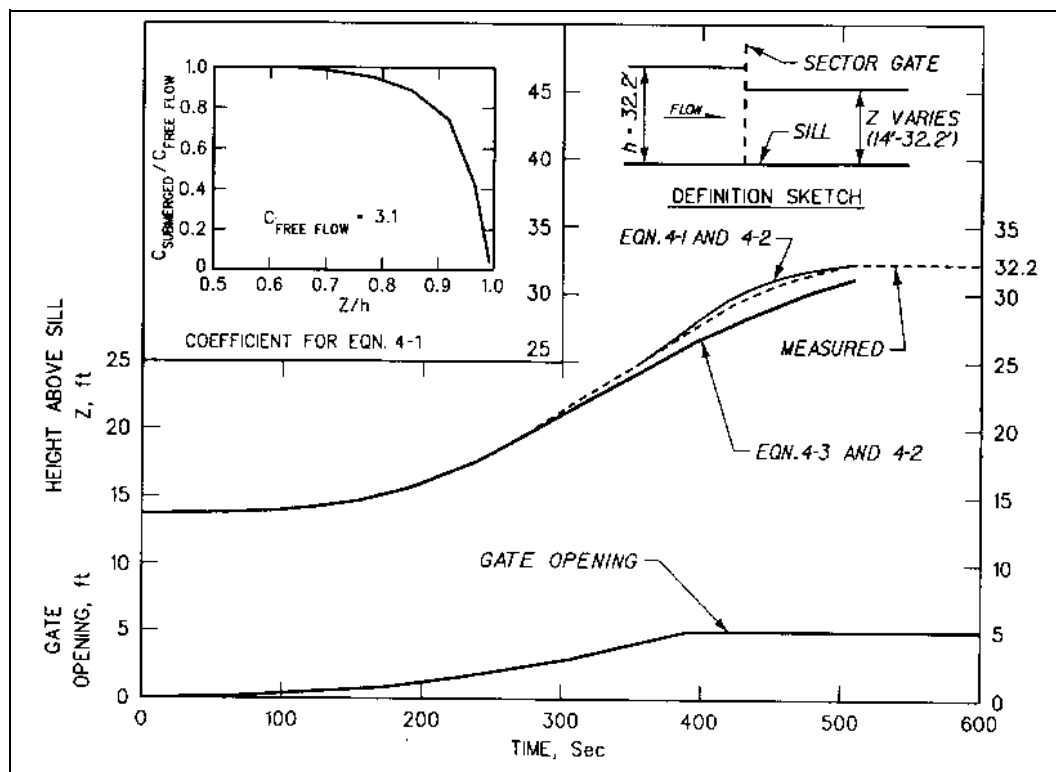


Figure 4-5. Example of Sector Gate Filling (Algiers Lock, Item 20)

construction drawings. Deviations from these details require site-specific hydraulic model studies.

4-17. Flow Passage Areas

The discharge orifice areas (chamber ports for filling and outlet ports for emptying) are primary elements for meeting operation time criteria. The most rapid systems are ones in which these areas are maximized while energy losses within the culverts and manifolds (and valving times) are minimized. Flow passage areas for five lock designs are listed in Table 4-6.

a. Filling. Systems that contract from main culvert to chamber (HB8 at Lower Granite) adapt to requirements for rapid filling by using relatively large culverts with minimum losses attributable to culvert features. Energy dissipation is primarily by baffling within the chamber. Systems that expand from main culvert to chamber (BL1, BL2, HB4) adapt to requirements for rapid filling by using relatively large ports with significant energy dissipation occurring within the culverts as well as within the manifold sections. For example, in the Barkley Lock prototype BL2 design (16 ports per lateral, 8 laterals per culvert) the loss is about three times greater

than for a streamlined system (item 71). Similarly, for the Greenup system (18 ports per lateral, 11 laterals per culvert) the loss is nearly six times greater (item 59).

b. Emptying. Chamber ports are inefficient as intakes. Efficient systems that contract from chamber to outlet (VB8 at Lower Granite) are designed for longer emptying than filling times and for energy dissipation concentrated downstream from the outlet. Expanding systems (SP at Ozark and VB4 at Bay Springs) tend toward more rapid emptying, although relatively greater losses are caused by chamber ports and manifolds. Deep submergence for water-surface elevations near upper pool reduces the possibility of cavitation within the chamber ports and manifolds during emptying.

4-18. Chamber Ports, Baffles, and Manifolds

Ports for SP systems are discussed in Appendix D. Port and manifold geometries, as used in BL1 and BL2 systems, are shown in Plate 4-1. For lateral systems, ports within a manifold are equally spaced on each wall and equally sized (2.08 ft high by 1.83 ft wide is common); the number of ports per manifold and the number of

Table 4-6
Flow Passage Areas

Description (Size = Width × Height, ft × ft)							
Location	Item	Ozark	Willow Island	Belleville	Willow Island	Bay Springs	Lower Granite
Chamber Ports	Type	SP	BL2	BL2	BL1	VB4	VB8
	Number, ^a N ₁	14	24	18	18	24	12
	Size (Face) ^b Size (Throat)	3.25 × 3.50 2.54 × 3.50	3.69 × 4.70 2.75 × 4.07	1.83 × 2.08 NA ^c	1.83 × 2.08 NA	1.5 × 3.5 NA	1.25 × 3.46 NA
Chamber Manifolds	Number, ^d N ₂	1	1	9	8	2	4
	Shape	Box	Box	Stepped	Stepped	Box	Box
Culvert	Size (Maximum)	12 × 12	16 × 18	8 × 5	8 × 5	14 × 9	14 × 9
	Size	12 × 12	16 × 18	15 × 16	14 × 16	14 × 14	12 × 22
Outlet Ports	Number, ^d N ₃	1	1	1	1	16	1
	Shape Size	Basin 17 × 12	Basin 20 × 16	Basin 19 × 16	Basin 20 × 16	Stepped 3 × 6	Basin 12 × 14
Operation	Evaluation	Area Ratios					
Filling	2 + 1	0.78	0.65	NA	NA	NA	NA
	3 + N ₁ × 1; 3 + N ₁ × 2	0.90; 1.16	0.69; 1.07	0.58	0.58	1.00	1.16
Filling	4 + N ₂ × 3	1.00	1.00	0.67	0.70	0.78	1.10
	4 + N ₁ × N ₂ × 1	0.90	0.69	0.39	0.41	0.78	1.27
Emptying	N ₁ × N ₂ × 1 + N ₃ × 5	0.78	1.30	2.04	1.72	0.88	1.24
	4 + N ₃ × 5	0.71	0.90	0.79	0.70	0.68	1.57

Notes:

- ^a Per manifold.
- ^b Excludes 0.5- to 1.5-ft radius surface contour.
- ^c Not applicable.
- ^d Per culvert.

manifolds vary between designs. The manifold roof is horizontal, whereas the interior sidewalls are stepped as shown. Port extensions are used when flow alignment, particularly from the upstream ports, during filling is of concern. Baffling is provided at adjacent manifold walls by offsetting ports between manifolds. Ports are chamfered with regard to outflow (filling) and inflow (emptying). Ports for high-lift designs (HB4 and HB8) experience high velocities and are chamfered for flow in either direction as shown in Plate 4-1. Tee baffle walls and baffles located on lock and culvert walls are required. The ratios of total port area to manifold areas are 1.000 and 0.865 for HB4 and HB8, respectively. These values near unity, similar to SP systems, are required for efficiency for bidirectional operation. Values substantially greater, 1.7 for the Greenup system shown in Plate 4-1, are efficient with regard to emptying (i.e., as an intake) but relatively inefficient for filling.

Section IV Outlet Systems

4-19. General

Discharge outlet systems are the orifice controls for the emptying operation. The dominant chamber performance constraint is operation time as affected by outlet sizing. The dominant downstream approach channel constraint is navigation facility as affected by discharge hydrographs and outlet location (paragraph 4-9). The following distinctions regard sizing:

a. Expanding systems. The outlet port area is made greater than the chamber port area normally for the purpose of decreasing operation time. Concurrently, greater energy losses occur within the system (i.e., the chamber ports are not efficient as intakes) so that outflow velocities are also decreased. Both effects are favorable for low-lift locks. For high-lift locks, low local pressures and high pressure fluctuations are associated with expanding high-velocity systems.

b. Contracting systems. The outlet port area is made equal to or less than the chamber port area. The common purposes are to raise the hydraulic grade line within the system and to reduce discharge rates within the approach channel at the expense of increased operation time. Contracting systems are best suited for high-lift designs and are rarely appropriate for low lifts.

4-20. Design Types

Outlet design variations occur because of options regarding location. General types are outlined in Plate 4-2 as follows:

a. Manifolds in approach channel floor. One or several manifolds from each emptying culvert extend across the approach channel. The Bay Springs design results in uniform transverse flow distribution near the lock. The new Bonneville design requires the channel expansion (as tested for the Dalles lock, item 52) to be initiated near the manifolds in order to attain a uniform flow within the approach channel. The new Bonneville system contracts (discharge port area to chamber port area ratio equals 0.83) whereas the Bay Springs system expands (ratio equals 1.14, item 78). The St. Anthony Falls Lower Lock is an example of large expansion and uses four lateral manifolds branching from one discharge culvert (item 44).

b. Manifolds in guide and guard wall. Two such expanding systems are shown in Plate 4-2. The Trinity River model test manifold discharges directly into the lock approach (item 74). The New Cumberland Main Lock discharge is subdivided by the main lock into river, main approach, and auxiliary approach components (item 21). The Trinity River system requires baffles at each port. These types of approach-channel manifolds are low cost and are well-suited for low-lift projects when higher velocities and turbulence in the approach near the lock are acceptable (as contrasted with remote outlets, *c* and *d* below).

c. Basins. Normally and when economically feasible, the most favorable outlet location as regards navigation is in the main river remote from the lock approach. Basins used for these outlets are as shown in Plate 4-2. The Greenup Lock type basin is relatively deeply submerged (item 43) so that energy dissipation within the flow exterior to the basin is acceptable. The Jackson Lock type is designed (item 32) as a stilling basin; test data pertain to designs without and with various spacings of baffle blocks and end sill. Lower Granite (high-lift) uses a Greenup-type basin with a contraction (discharge port area to chamber port area ratio equals 0.80). Ozark Lock (low-lift) uses a Jackson Lock unbaffled basin with an expansion (ratio equals 1.29).

d. Other types. The outlet may be placed (usually remotely) so that other outlet structures as used elsewhere (outlet works for example) suit a site-specific design. The structure must:

- (1) Provide conditions (particularly with regard to navigation) in the lower approach that are satisfactory.
- (2) Have expansion or contraction conditions between chamber manifolds and outlet that are acceptable with regard to chamber performance.
- (3) Provide a capability for reliably handling structural and hydraulic needs (particularly large intermittent discharges) during lock chamber emptying.

Section V Intakes

4-21. General

Intake flows are essentially unidirectional. The design pertains to filling only and seeks to accomplish the following objectives.

a. Navigation and sedimentation. The location and orientation are such that adverse effects on navigation and channel sedimentation are avoided (see constraints, Chapter 2).

b. Debris and ice. The elimination of debris from the culvert normally requires trashracks at the intakes. These are placed on the wall face (common) or immediately within the wall structure (Lower Granite, item 79). The reduction of clogging at the intakes and sediment transport into the culverts is of obvious benefit in terms of lock maintenance (see paragraph 3-13). Trashracks must be secured for small reverse loadings that occur during lock chamber overfill.

c. Velocities. The intake is designed as a highly convergent streamlined manifold having the concurrent objectives of equal flow distribution through the ports and small energy loss. Small energy loss contributes to efficient lock filling and, for two-culvert systems, enables equal culvert flows to be attained with substantially different intake configurations. Low velocities through the trashbars place less stress (and reduce the possibility of flow-induced vibration) on the exposed structural elements. Existing rack structures are generally conservative for peak velocities less than 4 feet per second

(fps); higher velocities may require special attention (EM 1110-2-1602; EM 1110-2-2602).

d. Vorticity. The formation of large vortices at lock intakes is considered highly undesirable because of hazard to small vessels, imbalance between culvert flows, and damage to trashrack. The elimination of vortex action for a specific filling pattern requires studies (see Chapter 5, Section VIII) of the following items:

(1) *Local geometry and flow constraints.* Geologic and structural features, such as the shape and orientation of guide and guard walls, may introduce vorticity into the intake flow. Similarly, adjacent spillway or river flows may result in vortex formation under a particular format of overall project operation. An intake located outside the approach channel so that navigation is not affected by vorticity over the intake structure is advantageous at many projects.

(2) *Structure type.* Generally, for small submergence, intakes are long and shallow with numerous ports (8-12 are not uncommon); a uniform distribution of flows over the length of the structure tends to reduce vortex formation. Short and high intakes (four ports at Lower Granite) may function satisfactorily when deeply submerged.

(3) *Submergence.* Deeply submerged intakes (see EM 1110-2-1602) are generally less prone to vorticity than these with shallow submergence. Extrapolating submergence effects based solely on changing upper pool levels as compared to changing intake elevation (with fixed pool level) is questionable because of local geometry.

(4) *Operation.* Vorticity intensifies as the valve is opened and persists during and sometimes beyond the lock-filling period. Operational situations, particularly valve opening times and maximum flow values, are important.

4-22. Design Types

Examples of intake structures are shown in Plate 4-3 with layout parameters listed in Table 4-7. These and other intakes have been studied (physical hydraulic models) and adopted for site-specific application.

Table 4-7
Examples of Model-Tested Intake Layouts^a

Lock	Lift ft	Q cfs	No. of Ports	Port		Manifold Length ft	Pier Thickness ft	Submer- gence ft
				Height ft	Width ft			
Holt	63.6	7,000	1	31	18	18	NA	46.5
Lower Granite	105.0	13,600	4	30	8	47	5	58.0
Greenup	32	7,000	8	12 ^b	8	99	5	14.0
Bay Springs	84	9,100	10	14	7	115	5	48.0
Dardanelle	54	6,000	13	13	7	151	5	24.0
Barkley	57	4,400	2 × 4	13	7.5	66	12	29.0
Dardanelle	54	6,000	2 × 7	13	7	79	5	24.0

Note:

^a Dimensions exclude rounding at the wall face.^b 4-ft-high sill, culvert at intake 18 ft wide by 16 ft high.

Section VI

Filling-and-Emptying Valve Systems

4-23. General

Recent lock designs use reverse tainter valves for flow control. Alternate valve types provide less desirable hydraulic, structural, operational, or economic conditions. The normal tainter valve (skinplate upstream) has been replaced for lock design by the reverse tainter valve (skinplate downstream) because of the ease of regulating air demand for the latter design. The normal valve is not precluded from lock design (particularly as an emptying valve); however, current practice is to use the reverse tainter valve for emptying as well as filling. Comprehensive design guidance presented in EM 1110-2-1610 provides details regarding valve types, loadings, losses, etc.; this discussion is limited to an overview of the valves as they relate to the overall filling-and-emptying arrangement. The following paragraphs deal exclusively with reverse tainter valves.

4-24. Valve Sizing

By using streamlined contractions upstream and gradual expansions downstream, the valves can be sized substantially smaller than the main culvert section. Section area changes commonly are accomplished by a change in culvert roof elevation rather than offsetting the culvert walls. Large valves (e.g., 18 ft high by 16 ft wide) are designed

for the *new* Gallipolis low-lift lock. The extreme contraction-and-expansion design is at the Lower Granite high-lift lock, which, for a 22-ft-high by 12-ft-wide main culvert, uses 14-ft-high by 12-ft-wide filling-and-emptying valves. The advantage of small valves is lower cost particularly, because of the greater loading, at high-lift projects. Higher velocities and lower pressures at the valve location occur for small valve designs during valve full open conditions.

4-25. Valve Siting

Structural, operational, and economic considerations for valve siting must satisfy the following hydraulics topics.

a. Position along the culvert. The filling valve, downstream from the intake manifold, and the emptying valve, upstream from the outlet, are separated from the culvert-to-chamber system by a streamlined transition conduit. The fundamental requirement is that the distribution of flow into and out of the culvert-to-chamber system is not unbalanced due to nonuniformity in the adjacent main conduit flow. Current guidance requires a distance of 6.5 culvert heights (as measured at the filling valve) between the filling valve and the culvert-to-chamber system (EM 1110-2-1610).

b. Elevation. The hydraulic consideration is pressure downstream from the valves that contributes to air entrainment and cavitation. Entrained air, particularly for

low-lift locks, may accumulate in the culverts as a pressurized air mass with the potential for bursting through the water surface and through vents and wells. Well-mixed air is more common for high velocities associated with high-lift locks and, when excessive, causes a frothy condition at the outflow water surface. Guidance on air entrainment is included in EM 1110-2-1610. Cavitation, particularly at high-lift locks, may cause surficial damage to culvert walls, valve seals, and other exposed valve components. A condition in which cavitation causes pressure shock waves to occur in the flow downstream from the valve is resolved during design by either air venting the low-pressure region below the valve so that air rather than vapor pockets occur; setting the valve at a low elevation so that vapor pressures do not occur; or using a less efficient system also so that vapor pressures do not occur. Guidance for avoiding cavitation is included in EM 1110-2-1610.

Section VII
Culvert Layouts

4-26. General

The culvert geometry includes bends, contractions, expansions, junctions, bifurcations, etc., as required to resolve the plan and profile layout of the intake, valves, culvert-to-chamber, and outlet systems. Recent designs use rectangular culverts. The aspect ratios (height to width) near 1.0 are common although values as extreme as 1.6 and 0.6 have occasionally been used. Ratios at the valve location (18:16, 14:12, 12:12, etc.) are always near unity for valve structure and economy reasons. Hydraulic design parameters, such as those included in

EM 1110-2-1602, are equally applicable to lock culverts provided allowance is made for the normally short spacing between components and the unsteady nature of lock flows. Published compilations (item M9, for example) and studies (item M5, for example) provide useful hydraulics guidance.

4-27. Contracting and Expanding Systems

System sizing (intake, filling valve, culvert-to-chamber, emptying valve, and outlet) establishes the extent of section area and shape changes within the culvert. These changes (examples are illustrated in Plates 3-3 and 3-4, SP systems; Plates 3-5 and 3-6, BL1 and BL2 systems; Plates 3-7 and 3-8, HB4 and HB8 systems) are particularly susceptible to separation at boundaries introducing energy loss, turbulence, and, particularly for high-lift locks, cavitation effects into the flow. To avoid these problems, expansions are normally gradual (roof expansions 1V:6H to 1V:10H are common) and contractions are streamlined. The flare of each SP port sidewall, for example, is about 3 degrees for filling; rounding at port intakes and outlets has ranged from about 0.5 to 2.0 ft.

4-28. Other Transitions

Numerous transitions have been used and tested for lock designs. Hydraulic model and prototype studies (see Appendix C) are sources of information regarding application or previous use in lock design. EM 1110-2-1602, other hydraulics design manuals, and published references (item M9, for example) provide useful guidance for hydraulic design.

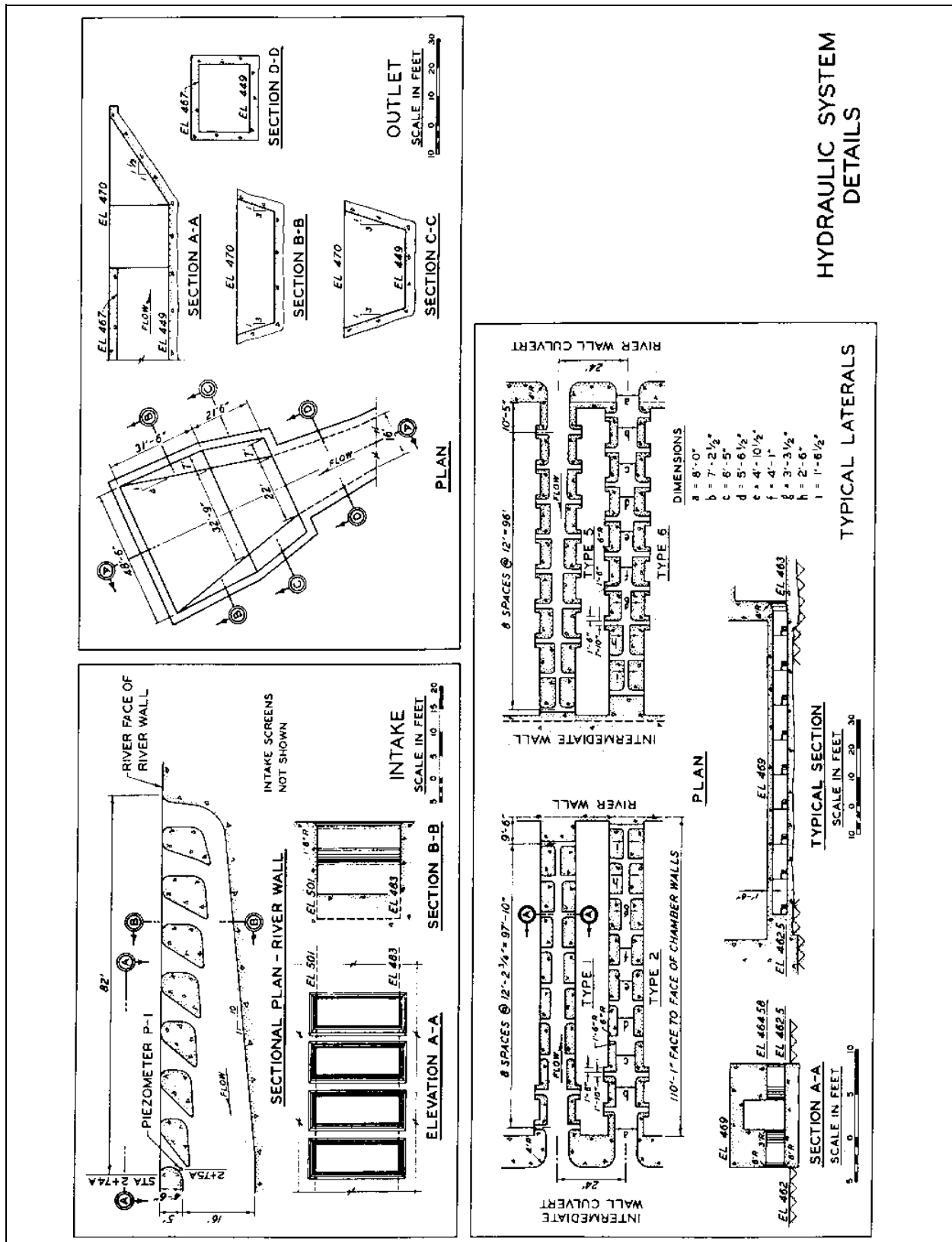
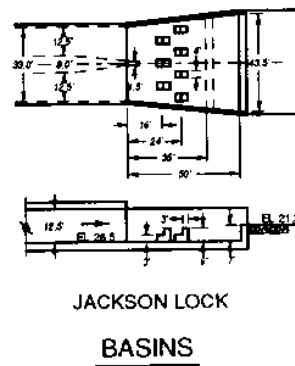
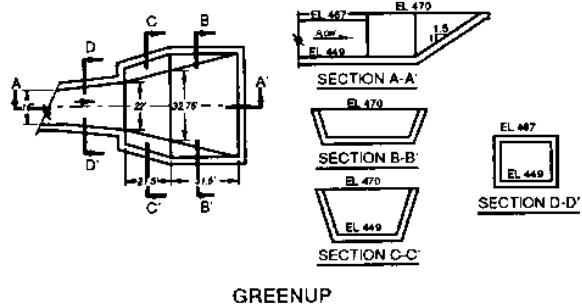
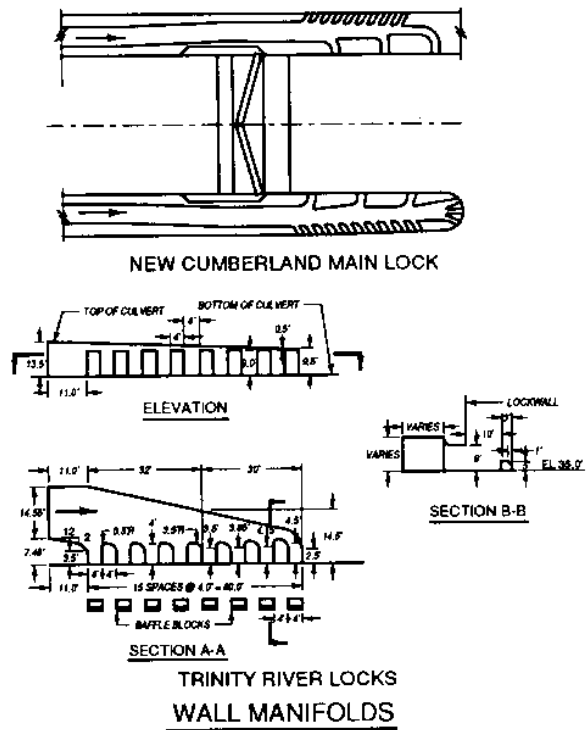
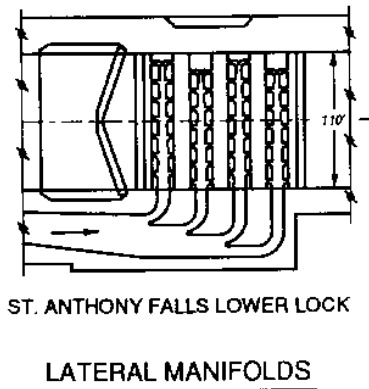
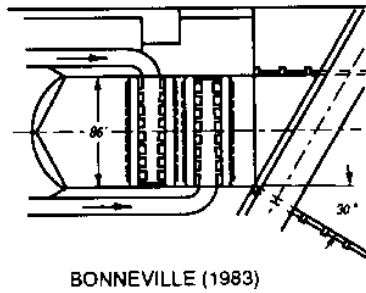
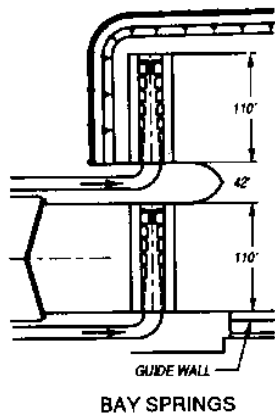


Plate 4-1



OUTLET TYPES

4-17